CLIMATIC VARIATIONS AND ECONOMIC CYCLES

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Since the publication of Brückner's widely known book on "Climatic Changes Since 1700"[1] there has been a strong and growing tendency to treat climate as a dynamic instead of a static geographical force. Because of its recurrent and, as yet, unpredictable variations it continually produces new and unforeseen results, whereas the static forces act uniformly, although man's power to utilize or overcome them may increase. This new conception bids fair to produce widespread effects not only upon geography, but also in the realms of history and economics on the one hand and of general biology on the other. Two admirable examples of the new tendency are afforded by the recent essays of Pettersson,[2] the director of the Swedish Hydrographic-Biological Commission, and of Moore,[3] professor of political economy at Columbia University. Pettersson treats of present climatic cycles as illustrated in the fisheries of the Baltic Sea, and of past cycles of greater amplitude as illustrated by the history of Greenland, Iceland, and Scandinavia during the period of climatic stress which culminated in the fourteenth century. Moore treats of the cycles of our own day and points out their dominating effect upon the march of prices and hence upon the economic currents of the United States.

To begin with Moore's work, since it lies closest to our own lives, he belongs to what we may call the geographical school of economists, who believe that the products of the soil are the ultimate foundation of the world's economic structure. He argues, as do all geographers, that since the productivity of the soil varies greatly from year to year for climatic reasons, especially because of changes in rainfall, climate must be one of the vital economic forces. He does not stop with the mere statement of his belief, however, as many geographers have done, but tests it by the most rigid mathematical methods. He selects the Ohio Valley and Illinois as two typical regions of great agricultural wealth where an intensive study of rainfall is likely to prove illuminating. His first object is to determine the periodicity of the rainfall, which he does by means of harmonic analysis based on Schuster's methods. He finds a very highly developed 8-year period and a less prominent 33-year period. On the basis of these two cycles and of their "semi-harmonics," or half periods, he reconstructs a "harmonic" rainfall curve. The next step is to examine the relation of

[1] Eduard Brückner: Klimaschwankungen seit 1700, nebst Beobachtungen über die Klimaschwankungen der Diluvialzeit. 324 pp. Diagrs. *Geogr. Abhandlungen*, Vol. 4, No. 2. Vienna, 1890.

[2] O. Pettersson: Climatic Variations in Historic and Prehistoric Time. 26 pp. Maps, diagrs., ills. Reprint from *Svenska Hydrogr.-Biol. Komm. Skrifter*, No. 5.

[3] H. L. Moore: Economic Cycles: Their Law and Cause. 149 pp. Diagrs. The Macmillan Co., New York, 1914.

crops to rainfall. He selects for this purpose the corn, oats, hay, and potatoes of Illinois, which together form over 96 per cent of the value of the crops of that state. By means of correlation coefficients he finds that the critical periods are as follows:

Crop	*Critical Period*	*Correlation Coefficients*
Corn	July, August	.589
Oats	May, June, July	.290
Hay	March, April, May, June	.620
Potatoes	July, August	.666

If temperature as well as rainfall were considered, the coefficients would doubtless be still higher, especially in the case of oats. Even as they stand they are so high as to indicate a very close relation between the size of the crop and the rainfall. Hence Moore constructs harmonic curves of the crops on the basis of the cycles used for rainfall, that is 8 and 33 years, and finds that they are very similar to the rainfall curves. It seems to the writer that the use of harmonic curves is one of several points in the book that deserve criticism because they are given as if they were parts of the main argument, although in reality they are not necessary and weaken rather than strengthen it. The curves add a difficult and somewhat obtrusive mathematical element which detracts from the main thought, and they do not bring out the facts so conclusively as would the actual curves properly smoothed.

In the next chapter Moore discusses the "law of demand." He shows that the staple food crops follow the usually accepted form of this law, namely, that an abundant supply causes a fall of price while a limited supply causes a rise. Within reasonable limits the price of wheat, for example, can be predicted provided the size of the crop is known; and the size of the crop can be predicted if the weather conditions are known. This brings us to the most important part of the book. Taking the whole country, Moore investigates the average yield per acre of nine staple crops, giving to each a weight proportional to its importance. He then demonstrates that, regardless of whether the acreage is larger or smaller, the price fluctuates in proportion to the yield per acre, which in turn varies according to the weather and especially according to the rainfall. The next step is to connect this result with other economic conditions in the realms of manufacturing and distribution.

Before doing this, however, Moore turns aside to another of the matters which seem both unnecessary and inconclusive. Economists have advocated the doctrine that a small supply causes a high price and vice versa, but the conditions prevalent during hard times are thought by Moore to contradict this. When business is at its worst and the supply of manufactured goods is at its least, the prices are lowest; while when times are good and all the factories are producing their maximum output, prices rise highest. It seems to the writer that there is no real contradiction between the commonly accepted economic law and Moore's new interpretation. In the case

of crops the *supply* is the determining factor, and the price goes down when the supply is abundant. In the case of other articles the *demand* is the ruling element; the price goes down when poor crops not only make the farmer poor but compel the laborer to pay high prices for food, and thus decrease the demand for manufactured goods. It is worth while to emphasize this point because Moore's book is so important that it is sure to be widely criticized, and this is one of the easiest avenues of attack. Yet so far as the fundamental conclusions are concerned the book is so firmly grounded on a vast body of facts that its main line of argument seems unassailable. Hence this review attempts to brush aside, as it were, the parts that may arouse criticism, but which are irrelevant to the main geographical argument.

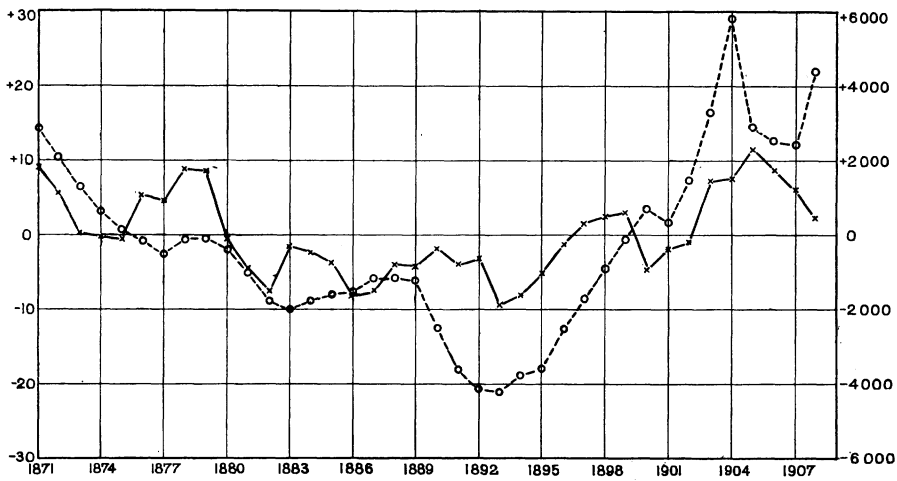

FIG. 1—Relation between cycles of yield per acre of crops (x—x—x) and cycles of the production of pig-iron (o---o---o), a lag of two years in the production of pig-iron having been eliminated. (Based on Fig. 23 in Moore's "Economic Cycles.")

The figures on the left and right represent the deviation of the yield of crops per acre and of the production of pig-iron from their respective secular trends.

To return to the outline of the book, a detailed study of pig iron, the "barometer" of trade, shows unmistakably that its price goes down when that of food products goes up, and vice versa. It does not feel the effect of scanty crops immediately, however, for there is a lag of between one and two years. The relationship is illustrated in Figure 1. The last point considered by Moore is the relation of general prices to crops and hence to weather. By means of the index numbers of "all commodities" prepared by Falkner from 1870 to 1890 and by the Bureau of Labor since 1890 he constructs the curve of general prices marked with circles in Figure 2. In this, as in the other curves, the secular change, that is, the effect of the depreciation of gold in the case of general prices and the effect of improved methods of agriculture in the yield of crops, has been eliminated.

Also the curve of prices has been pushed back four years so that what appears as 1871 is really 1875. This is legitimate. The production of pig iron is, as it were, the preliminary step in all manufacturing. If it shows a lag of one or two years, a lag of twice as much is to be expected in commodities whose production requires a much greater number of stages between the raw material and the finished products.

Moore's final conclusions may be summed up in his own words: "In the introduction to this essay it was observed that economic dynamics stand in need of a law that shall be to a changing society what the law of diminishing returns is to a society in a relatively static state. We may now formulate the law: The weather conditions represented by the rainfall in the central part of the United States, and probably in other con-

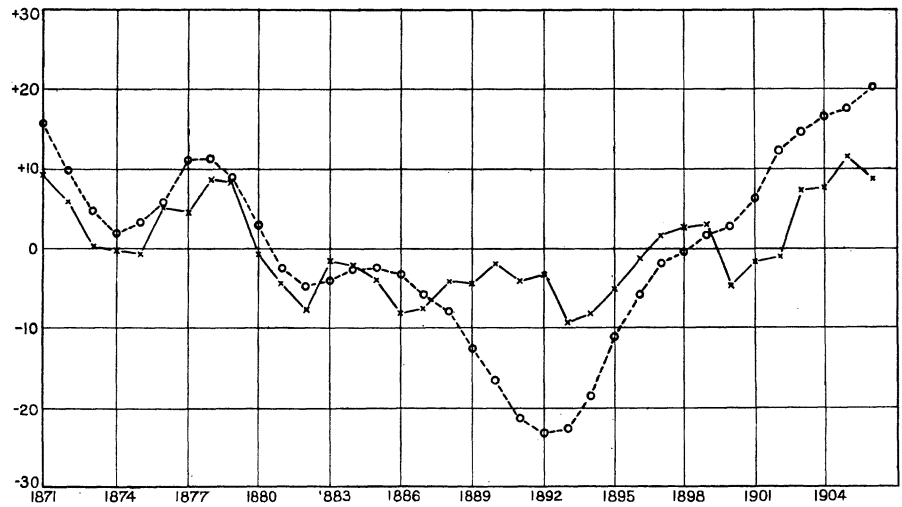

FIG. 2—Relation between cycles of yield per acre of crops (x—x—x) and cycles of general prices (o---o---o), a lag of four years in general prices having been eliminated. (Based on Fig. 27 in Moore's "Economic Cycles.")

The figures on the left represent the deviation of the yield of crops per acre and of the index of general prices from their respective secular trends.

tinental areas, pass through cycles of approximately thirty-three years and eight years in duration, causing like cycles in the yield per acre of the crops; these cycles of crops constitute the natural, material current which drags upon its surface the lagging, rhythmically changing values and prices with which the economist is more immediately concerned. . . . The principal contribution of this essay is the discovery of the law and the cause of economic cycles. The rhythm in the activity of economic life, the alternation of buoyant, purposeful expansion with aimless depression, is caused by the rhythm of the yield per acre of the crops; while the rhythm in the production of the crops is, in turn, caused by the cyclical changes in the amount of rainfall. The law of the cycles of rainfall is the law of the cycles of crops and the law of economic cycles."

It may be questioned whether Moore is really the discoverer of this law. Clayton[4] announced it in 1901 in his paper on rainfall and commercial crises. Brückner,[5] in his work on the relation of rainfall to immigration and economic distress, has stated it in effect, although not with the definite label of "law." Other geographers have discussed it under other forms, so that it may be regarded as an integral part of current geographical thought. Moore appears to have been so busy in the laborious preparation of his admirable tables that he has failed to find out how much has been done by his predecessors. Yet, after all, such criticism is of minor importance. Moore has gone much farther than his predeces-

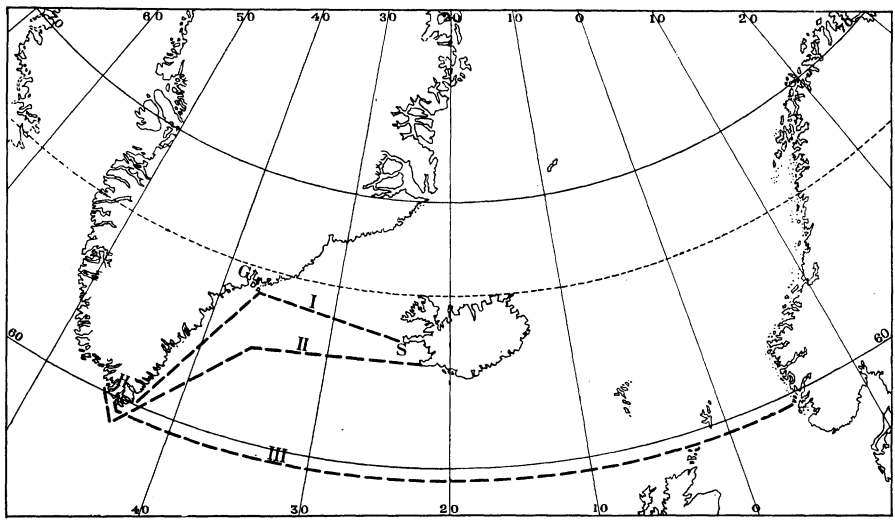

FIG. 3—Old Norse sailing routes to Greenland. (Based on a figure in Pettersson's "Climatic Variations in Historic and Prehistoric Time.")

I, Eric the Red's route on his voyage of discovery, which became the regular route followed from 1000 to 1200; II and III, sailing routes from 1200 to 1400 according to the old sailing directions of Ivar Bårdsson. S, G, H are localities; S, Cape Snæfell on the western coast of Iceland; G, Gunbjörnskær, and H, Hafhverf, on the coast of Greenland.

sors and has removed his subject from the realm of probability to that of almost absolute certainty. Hereafter there can be little question that apart from such influences as the depreciation in gold, or great calamities like the war, the general trend of economic conditions in this country is closely dependent upon cyclical variations in the weather.

Turning now to the work of Pettersson, we find the same conclusion

[4] H. H. Clayton: Influence of Rainfall on Commerce and Politics, *Popular Science Monthly*, Vol. 60, 1901, pp. 158-165.

[5] Klimaschwankungen und Völkerwanderungen im XIX. Jahrhundert. 8 pp. *Internat. Wochenschr. für Wiss., Kunst und Technik*, March 5, 1910.

Klimaschwankungen und Völkerwanderung. Vortrag gehalten in der . . . K. Akademie der Wissenschaften am 31. Mai 1912. 24 pp. Vienna, 1912.

The Settlement of the United States as Controlled by Climate and Climatic Oscillations. *Memorial Vol. Transcontinental Excursion of 1912 of Amer. Geogr. Soc.*, pp. 125-139, New York, 1915.

under another guise. The period of climatic instability which culminated in the fourteenth century appears to have been to all intents and purposes a phase of a cycle resembling those shown in Moore's curves, but on a much larger scale. It produced correspondingly great results. Pettersson gathers the evidence of this cycle from the level of the Caspian Sea, the conditions of Lop Nor and other parts of Central Asia, the growth of the Big Trees of California, the history of Yucatan, and the records of great storms, disastrous floods, and unprecedentedly cold winters in northwestern Europe. His main discussion, however, relates to Greenland and the Vikings.

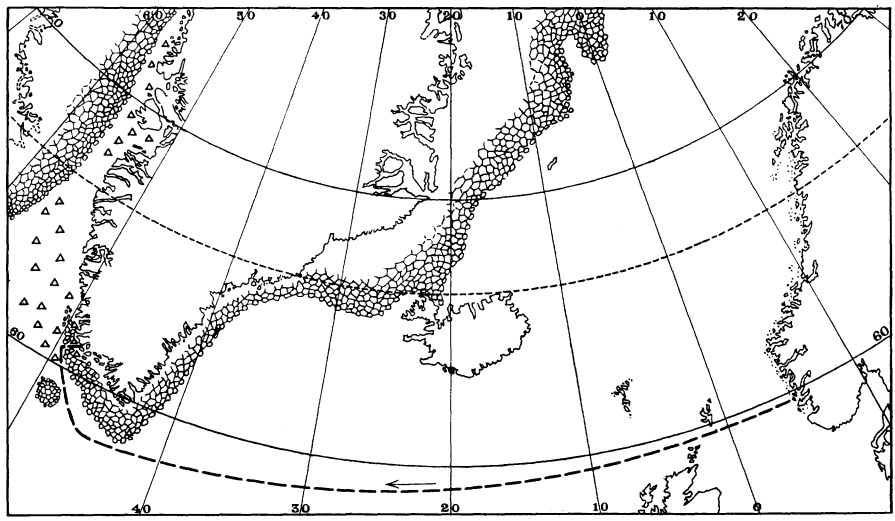

FIG. 4—Present sailing route from Norway to Greenland. (Based on a figure in Pettersson's "Climatic Variations in Historic and Prehistoric Time.") The shaded areas indicate the limit of pack ice and solid drift ice.

When Eric the Red first went from Iceland to Greenland in 982 A. D. he does not seem to have been troubled by ice. The sailing directions preserved in the old sagas show that ships at first went nearly westward from Iceland to the coast of Greenland, then southward along the coast, and through the strait which separates the island of Cape Farewell from the mainland (see Fig. 3). Such a course is now impossible because of the accumulation of floating ice (Fig. 4), yet the earlier sagas make no mention of any such hindrance. In the thirteenth century, however, there appears a warning not to make the east coast of Greenland too soon on account of the ice, while a little later the old course was completely abandoned, and ships dared not try to reach the coast of Greenland except at the southern tip or a little way northward on the west side where ice is still comparatively scarce.

Other facts bear out the conclusions derived from the ice. The sagas speak of abundant fruit of excellent quality in the warmer inner valleys

of southern Greenland, and figures are in some cases given as to the numerous cattle. Such fruit will not grow now, and the number of cattle at present is probably not over a hundred, although the population is as great as in the days of the Vikings. There is not sufficient pasturage for more. Another important fact is that ruins of old Norse villages are tucked away in almost inaccessible spots at the base of the glaciers or else in places where the level land is practically covered by ice. The Eskimos say that there are ruins of houses and churches under the ice. All these things point to a marked advance of the inland ice sheet since the days of the Vikings. The worst time seems to have been in the fourteenth century. Ships then found it difficult to reach Greenland, and the colonists were largely left to themselves. The Eskimos, too, who had previously not been troublesome, began to make raids. Pettersson thinks that this was due to the fact that the northern waters where the Eskimo had been accustomed to fish became covered with ice. Therefore economic distress began to render the people discontented and violent, and at length they raided the Norseman in answer to the demands of hunger. One of the main Norse settlements was wiped out in 1342, the other and larger disappeared after 1418.

In explanation of the mechanism of the climatic change culminating in the fourteenth century Pettersson says[6] that in the days of Greenland's prosperity "the powerful Labrador Current carried no ice . . . or, in any case, nothing comparable to the present quantity. This again reacted on the Gulf Stream. It is the drift ice of the Labrador Current which attacks the Gulf Stream south of Newfoundland and compels its warm water to spread eastward towards the submarine base of the Azores and the coastal bank of Europe. There it is joined by the warm outflow from the Mediterranean, which .... (extends) as far as the west coast of Ireland and forms the vast area of warm water over which the great low-pressure belt south of Iceland forms in winter. When no ice was carried by the Labrador Current and this current consequently played a less conspicuous part in oceanic circulation, the Gulf Stream 'could take a more westerly course,' as Ekholm says. Then the ice-melting took place in higher latitudes, in Baffin's Bay, in the Arctic Sea, and even in the Polar Basin. Western and northwestern Europe then possessed a more continental climate with colder and calmer winter weather."

In Norway the effect of the stormy climate of the fourteenth century, which succeeded the conditions just described, was almost as disastrous as in Greenland. Dr. Bull of Christiania is quoted by Pettersson[7] to the effect that the decay of the Norwegian kingdom at that time was not so much a consequence of political conditions as of the frequent failures of the harvest, so that grain for bread had to be imported from Lübeck, Rostock, Wismar, and other places. "The Hansa Union undertook the importation and obtained political power by its economic influence. The Norwegian

[6] *Op. cit.*, pp. 21-22. [7] *Op. cit.*, p. 22.

land-owners were forced to lower their rents. The population decreased and became impoverished. The revenue sank 60 to 70 per cent. Even the income from Church property decreased. In 1367 corn was imported from Lübeck to a value of 500,000 kroner. The trade balance inclined to the disadvantage of Norway, whose sole article for export at that time was dried fish. Dr. Bull draws a comparison with the conditions described in the sagas when Nordland [on the Arctic Circle] produced enough corn to feed the inhabitants of the country. In the time of Asbjörn Selsbane the chieftains in Trondenäs [still farther north, in latitude 69°] grew so much corn that they did not need to go south to buy corn unless three successive years of dearth had occurred. The province of Trondhjem exported wheat to Iceland and so on. Probably the turbulent political state of Scandinavia at the end of the Middle Ages was in a great measure due to unfavorable climatic conditions, which lowered the standard of life, and not entirely to misgovernment and political strife, as has hitherto been taken for granted."

Evidently the economic law here illustrated by Pettersson is the same as that found in America by Moore, but with appropriate modifications, because conditions of abundant rainfall that are favorable in the central United States are unfavorable in Scandinavia and Greenland. If Norway had not suffered such distress she might have been able to succor her colonies across the Atlantic and save them in spite of the Eskimos. If that had happened the history of America would assuredly have been different.

Pettersson's paper is of great value not merely for its discussion of the economic effects of climatic cycles but for its suggestions as to the cause of such cycles. A prolonged series of oceanographic studies has led him to the discovery that variations in tidal intensity, due to the relative position of the moon at perigee and apogee, can be detected in the flow of water into the Kattegat and Baltic as determined by the level at which a certain salinity is found. They can also be detected by means of the migrations of fish, especially herrings. The smallest main cycle lasts eighteen years. In the part of this cycle when the tides are strong and the currents from the Atlantic consequently extend far toward or into the Baltic, the fish move in the same direction. The number of herrings caught off the southwest coast of Sweden is almost invariably at a maximum when the tide-generating forces are at a maximum, but greatly declines when the force is at a minimum,—another striking influence of the control of a dynamic geographical environment over economic conditions.

A study of wider periodicities of the tides shows that the perigee of the moon and the perihelion of the earth coincide in direction once in about 1,800 years, or, specifically, about 3500 B. C., 1900 B. C., 250 B. C., 1433 A. D., and 3300 A. D. At such times, since the tide-raising bodies are nearer to the earth than usual, their combined forces when the moon is at

its greatest declination cause unusually high tides. This must cause unusually strong currents into the Kattegat or even the Baltic. That such is the case is indicated by the fact that in the Middle Ages from 1100 to 1500 A. D. a highly prosperous herring fishery existed in the Öresund between Copenhagen and the Swedish shore, while later it moved gradually northward into the northern Kattegat and the North Sea. As further proof of the strength of the tides Pettersson points out the many instances in which the waves overwhelmed the coasts of the Netherlands and of eastern England from the thirteenth to the fifteenth centuries. Apparently the extraordinarily high tides, joined with storms of unusual severity, were the reasons why the Zuyder Zee and other lowland tracts became permanent parts of the North Sea through the breaking down of the barriers of sand dunes that had previously protected them. On our own shores it is probable that similar high tides may account for many of the supposed evidences of an uplifting of the coast.

Thus far Pettersson's reasoning seems convincing. It is not so easy to accept his conclusions when he attributes the sharp climatic change of the fourteenth century to the effect of the tides. He thinks that the tides may have generated currents so strong that they appreciably influenced the distribution of water of various temperatures and thus altered the wind system. For instance, he shows that a larger influx of the dense salt brine of the Atlantic through the Kattegat would diminish the thickness of the light layer of comparatively fresh water which floats on top of the Baltic and forms an outward current at the Kattegat in the opposite direction from the lower current. If the fresher layer were thin, it would become cold throughout its whole mass more quickly than now and hence would be more likely to freeze. In this way a part at least of the recorded freezings of the Baltic during the Middle Ages may perhaps be explained. The tides may also have had much to do with the increased quantity of drift ice along the eastern Greenland shore in the fourteenth century and thus may have had some influence upon the location of the Gulf Stream and of the North Atlantic low-pressure area. It is worth noting that there is considerable evidence that the climatic cycle which reached a maximum in the fourteenth century appears to have been of a much more severe character than the one which caused the trees of California to grow rapidly in the tenth century. To carry this farther, however, and to suppose that tidal changes could radically alter the rainfall of California or of the far interior of Asia seems scarcely probable. Moreover, the periodicity of climatic changes indicated by the trees of California or by the lakes of Central Asia does not harmonize with the periods of the tides. Apparently climatic fluctuations are due to some other cause, which in the Middle Ages chanced to coincide with a tidal maximum.

Even though we may reject Pettersson's broader conclusion as to the effect of tides on climatic cycles, it seems highly probable that he has

discovered one of the minor causes, which, like volcanic eruptions, play an important part at certain times and places. Geologists have been prone to think that with the lapse of Croll's hypothesis of the effects of the precession of the equinoxes upon glaciation there remained no important astronomical hypothesis based upon the movements of the earth and sun. Pettersson's work shows that this is by no means the case. His astronomical calculations are unassailable, and he finds definite terrestrial results corresponding to expectations.

In this connection it may not be amiss to call attention to two other astronomical hypotheses which are advocated in recent publications. They fail to receive much consideration because they depend on abstruse calculations upon which only the astronomer can pronounce judgment. One is the theory of Drayson, set forth in a book called "Draysonia" by A. F. R. de Horsey[8] and recently advocated in numerous articles by R. A. Marriott.[9] The gist of this is that unexplained but widely recognized discrepancies in the calculations of the obliquity of the earth's axis are due to the fact that the obliquity actually varies from a minimum of 23° 25′ 47″ to a maximum of 35° 25′ 47″ in a period of 31,682 years. Such a change would have brought the Arctic Circle down to the latitude of northern England about 13,500 B. C., and would unquestionably have produced marked climatic results. The geological as opposed to the astronomical arguments advanced in support of this hypothesis are not convincing. For instance, they pay no attention to glacial stages and other minor climatic cycles such as the one discussed by Pettersson. Nevertheless until astronomers agree as to the cause and extent of the variation in the obliquity of the earth's axis, we cannot say absolutely that this hypothesis is to be discarded.

Another hypothesis of the same kind is that of F. J. B. Cordeiro.[10] He holds that since the earth is acknowledged by physicists to be slightly elastic and not absolutely rigid, it must possess a gyroscopic motion. If this is so, it appears that the obliquity of the earth's axis must be subject to a secular variation of long period. This, Cordeiro holds, would cause the obliquity to vary from zero, at which time a warm climate would prevail at the poles, to an angle greater than that of the present time, which would give rise to glaciation. The movements back and forth must in any case be extremely slow, much slower than those postulated by Drayson. The testing of this hypothesis demands such abstruse calculations that no one but a highly trained mathematician can follow them. Moreover, the variables are so numerous that only the broadest approximations are possible.

The reason for introducing these hypotheses here is that such work as

[8] vii and 76 pp. Diagrs. Longmans, Green & Co., New York, 1911.

[9] *E. g.*, Changes of Climate: The Glacial Period Explained, *Candid Quart. Rev.*, 1914, August, pp. 757-782. Letchworth, England.

[10] The Gyroscope. vii and 105 pp. Ills. Spon & Chamberlain, New York, 1913.

that of Moore and Pettersson is rapidly leading to the conclusion that climatic cycles of all grades are of great importance, not merely in geological times, as has long been recognized, but in human history and in our own personal affairs. Therefore the necessity of understanding their causes is correspondingly urgent. We cannot reach a true solution unless the many possibilities are viewed without bias. The carbonic acid hypothesis, the hypothesis of crustal deformation, the solar hypothesis in its various forms, and the volcanic hypothesis are all before us. The work of Pettersson, together with the other more tentative hypotheses described above, suggests that the purely astronomical hypothesis must also be considered. In its lunar form it offers explanations of small phenomena with cycles varying from 3 to 1,800 years and in its other forms it offers explanation of cycles of 30,000 or more years, and of those of still greater magnitude. Such cycles have apparently existed, whatever may be their cause. Their economic effects upon man, and the corresponding effects upon plants and animals, must have been vital.